Simplified Interpretation of Pacemaker ECGs

Aaron B. Hesselson, MD, BSE, FACC
Assistant Clinical Professor of Medicine
Wayne State University School of Medicine
Detroit, Michigan

Futura, an imprint of Blackwell Publishing
Simplified Interpretation of Pacemaker ECGs

Aaron B. Hesselson, MD, BSE, FACC
Assistant Clinical Professor of Medicine
Wayne State University School of Medicine
Detroit, Michigan
For Heather
Within the past three decades, pacemakers have evolved from fixed-rate, single-chamber units to incredibly sophisticated dual-chamber devices that are capable of many different pacing modalities, that provide physiologic response to exercise or stress using a variety of sensors, and that also provide various diagnostic capabilities. These advances in technology have been accompanied by an inevitable increase in the complexity of ECG interpretation of pacemaker-generated rhythms. For those not directly involved in the management of pacemakers, the attainment of the skills needed to interpret pacemaker ECGs has been a daunting task.

With the availability of *Simplified Interpretation of Pacemaker ECGs*, a previously daunting task is now simple and painless. The reader is led step-by-step through all of the information needed to interpret pacemaker ECGs. After a brief refresher course on basic ECG interpretation, the reader is provided with an overview of the conduction system of the heart. The hardware associated with pacing is then reviewed, followed by an explanation of sensing and pacing function of pacemakers. Next is an explanation of the most common pacing modalities in a fashion that is simple to understand, yet thorough enough to make pacemaker ECG interpretation easy. This is followed by a very useful section dealing with miscellaneous topics such as automatic threshold determination, electromagnetic interference, and the use of pacing for indications other than bradycardia. The text ends with a series of case studies that brings together all of the information learned and provides the reader with a self-assessment of the topics that may need additional review.

The text is replete with schematic illustrations, charts, and ECG recordings that greatly enhance the learning experience. Furthermore, the reader is frequently challenged to answer questions that reinforce the material learned in a particular section.

Dr. Hesselson has succeeded admirably in distilling a potentially confusing body of knowledge into a simple-to-understand and palatable programmed text that is fun to go through. He could have
entitled the book *Pacemakers for Dummies*. With the few hours of time needed to go through this book, no one need feel like a “dummy” when faced with a pacemaker ECG.

Fred Morady, MD  
Professor of Medicine  
Director, Clinical Electrophysiology Laboratory  
University of Michigan Medical Center  
Ann Arbor, MI
Preface

It was 12 years ago that I began working in my first job out of college as a clinical pacemaker research engineer at Beth Israel Medical Center in Newark, NJ. Not having much experience with ECG interpretation I was given a basic text to read and learn. Soon after that I was ready to begin learning pacemaker ECG interpretation, and was surprised to find out that a similar basic text solely dedicated to pacemaker ECGs did not exist. Instead I was given technical manuals, proprietary “learning manuals” from various pacemaker manufacturers, and a pacemaker with a heart rhythm simulator to work with. For an engineer these were not difficult to use and understand.

Having since gone to medical school and trained as an internist, cardiologist, and now cardiac electrophysiologist, I have found that this lack of a basic pacemaker ECG interpretation text still exists. This book intends to change that. It has been written with a few thoughts in mind: “what would I have wanted in my hands when I was just beginning to learn pacemaker ECGs?” and “keep it as simple as possible so that not only an engineer, but also nurses, technicians, and even physicians can follow.” I have attempted to concentrate on the ideas that I found best in my experience. As such, there is an enormous emphasis placed on knowing a few basic parameters of the pacemaker system and their relation to the patient’s native heart rate and integrity of conduction from atrium to ventricle. The book requires that one already have a working knowledge of basic non-pacemaker ECG interpretation. Once studied, even fairly difficult pacemaker ECGs should be appropriately interpreted.

As one will see when reading the text, the figures are not numbered. Each image is placed in direct proximity to the text that refers to it. Also, there are fill-in-the-blank questions, with answers in boldface directly below, following most paragraphs. This “programmed teaching” style is done to emphasize salient points in the preceding text. In order to help maintain this format, there may
be empty areas on some pages. One may optimally use these spaces for study notes.

Some pacemakers have functions that are peculiar to the individual model and that may affect the ECG. Such details are not emphasized here. Consulting the technical manual that comes with each pacemaker, the local pacemaker ECG guru (EP attending, nurse, whoever), or pacemaker manufacturer technical service/sales representative is helpful in this regard. Good luck!
Acknowledgments

The following were instrumental influences, without whom this book would not be possible: Victor Parsonnet, MD; Alan D. Bernstein, EngScD; Donna Neglia, RN; Esther Schilling, RN; Ralph Gallagher; Thomas M. Bashore, MD, Robert Sorrentino, MD; Ruth Ann Greenfield, MD; and Matthew Flemming, MD.
Contents

Foreword .................................................................................................................. v
Preface .................................................................................................................... vii
Acknowledgments ................................................................................................... ix

Section I
The Basics

Chapter 1. Basic ECG Refresher ............................................................................ 3
Chapter 2. What Is a Pacemaker? ......................................................................... 21
Chapter 3. Pacemaker System and Cardiac Anatomy ........................................... 25
Chapter 4. The Hardware ..................................................................................... 27
  The Pacemaker Generator ................................................................................. 28
  The Pacemaker Lead ....................................................................................... 31
  The Pacemaker Programmer .......................................................................... 34
  The Pacemaker Magnet ................................................................................. 39
Chapter 5. Electronics 101 ................................................................................... 41
  The Electrogram .............................................................................................. 49
Chapter 6. Sensing and Sensitivity ...................................................................... 51
Chapter 7. Pacing and Capture ........................................................................... 55
Chapter 8. Rate Versus Interval .......................................................................... 61
Chapter 9. The Code and Mode .......................................................................... 65

Section II
The Modes

Chapter 10. VVI Pacing ....................................................................................... 73
  VVI Timing ...................................................................................................... 75
  Rate Modulation ............................................................................................. 81
  Magnet Mode (VOO) ....................................................................................... 82
Chapter 11. AAI Pacing ....................................................................................... 85
  AAI Timing ..................................................................................................... 87
Rate Modulation ................................................................. 91
Magnet Mode (AOO) ........................................................... 92
Chapter 12. DDD Pacing ......................................................... 95
  DDD Timing ...................................................................... 97
  Upper Rate Behavior ......................................................... 113
  Pacemaker-Mediated Tachycardia ...................................... 115
  Mode Switching ............................................................... 117
  Rate Modulation .............................................................. 118
  Magnet Mode (DOO) .......................................................... 120
Chapter 13. VDD Pacing ........................................................... 121
  VDD Timing .................................................................... 124
  Upper Rate Behavior/Mode Switching ............................... 133
  Magnet Mode (VOO) ......................................................... 135
Chapter 14. DDI Pacing ........................................................... 137
  DDI Timing .................................................................... 139
  Rate Modulation .............................................................. 151
  Magnet Mode (DOO) .......................................................... 153
Chapter 15. DVI Pacing ........................................................... 155
  DVI Timing .................................................................... 158
  Rate Modulation .............................................................. 167
  Magnet Mode (DOO) .......................................................... 168

Section III
Unusual Pacing Situations and Alternate Applications of Permanent Pacing

Chapter 16. Unusual Pacing Situations ...................................... 171
  Diagnostic Pacing Modes .................................................. 172
  Pacing to Prevent Atrial Fibrillation ................................... 174
  Transcutaneous Pacing ...................................................... 175
  Automatic Threshold Determination .................................. 176
  Diagnosis of Myocardial Infarction ..................................... 177
  Effects of Electric Cautery on Pacing ................................. 179
Chapter 17. Alternate Applications of Permanent Pacing ........ 181
  Pacing for Hypertrophic Obstructive Cardiomyopathy .......... 182
  Pacing for Ventricular Tachycardia .................................... 184
  Pacing for Heart Failure .................................................. 186
  Pacing for Syncope .......................................................... 188
Section IV
Case Studies

Chapter 18. Case Studies Part A ................................. 193
    Case Studies 1 through 7

Chapter 19. Case Studies Part B ................................. 205
    Case Studies 8 through 43

Index ........................................................................ 277
Section I

The Basics
Chapter 1

Basic ECG Refresher
It is strongly suggested that one master basic non-pacemaker electrocardiograph (ECG) interpretation before beginning pacemaker ECG analysis. What follows in this section is not meant to provide that skill. Rather this “refresher” is meant to highlight some areas of ECG interpretation that may be pertinent to understanding pacemaker rhythms and device function. Those who already feel comfortable in their non-pacemaker ECG interpretative skills should proceed beyond this section.

**ECG “Anatomy”**

The sinus or “SA node” is the heart’s own pacemaker that, in normal circumstances, initiates the heartbeat. From this native activation first the right (RA) and then left atrium (LA) are stimulated to contract. This activation is noted on the ECG as a “P wave.”

![Heart Diagram](image)

Atrial electrical activation is represented on the ECG by the ________.

The structure in the RA that normally initiates the heartbeat is the ________.

**P WAVE**

**SA or SINUS NODE**
After atrial activation, the “atrioventricular (AV) node,” followed by the “His bundle,” and then the “left (LBB)” and “right (RBB) bundle branches” become electrically stimulated. This results in left (LV) and right (RV) ventricular contraction, and is noted on the ECG as a “QRS” complex.* The ventricles then relax after contraction. This event, “ventricular repolarization,” is noted on the ECG as the “T wave.”

The QRS complex on an ECG represents _______ electrical activation.

Ventricular _______ is seen on the ECG as the T wave.

**VENTRICULAR REPOLARIZATION**

*QRS is a generic term that refers to the ventricular complex on the surface ECG. Not every QRS complex has all three components: Q wave (the initial negative deflection), R wave (the initial positive deflection), and S wave (negative deflection after an R wave). In some cases there is a second positive component termed R’.
How Fast Is It?

An easy method for determining how fast the heart rate is, on a standard speed ECG grid, is to find a QRS complex on a heavy grid line and note where the next QRS falls. The subsequent heavy grid lines after the first correspond to heart rates of 300, 150, 100, 75, 60, and 50 beats per minute (bpm), respectively. By memorizing this grid line progression, quickly approximating heart rate becomes simple!

The heart rate when a second QRS complex occurs four heavy grid lines after the first is ________.

A heart rate of 150 bpm would occur when two QRS complexes occur ________ heavy grid lines apart.

75 bpm
2
SELECTED ARRHYTHMIAS

Normally the sinus node causes the heart to beat anywhere between 60 and 100 bpm at rest. When the sinus rate is less than 60 bpm the rhythm is termed “sinus bradycardia.”

![ECG Graph 1](image1)

When the sinus rate is greater than 100 bpm the rhythm is termed “sinus tachycardia.”

![ECG Graph 2](image2)

Sinus rhythms that are less than 60 bpm and greater than 100 bpm are, respectively, called sinus _______ and _______.

BRADYCARDIA, TACHYCARDIA
It can rarely happen that neither the sinus node nor any other site in the atria initiate a heartbeat. In this instance the ventricles may respond, on their own, with what is called a "junctional" heart rhythm. The rate is typically less than 60 bpm and can frequently require pacemaker treatment!

![ECG Image]

Even rarer is the occurrence of a complete lack of heart rhythm or "asystole." Asystole may occur in the setting of significant cardiac abnormalities and frequently demands a pacemaker to help maintain a heart rhythm.

![ECG Image]

A junctional rhythm may result when no ______ site initiates a heartbeat.

_______ is the term used to define a complete lack of a heart rhythm.

**ATRIAL ASYSTOLE**
The most common abnormal heart rhythm is “atrial fibrillation” (AF). It occurs when numerous sites in the atria other than the sinus node fire at the same time to make the atria beat. A rapid chaotic atrial rhythm that has an irregularly irregular characteristic to its conducted ventricular rate is the usual result. Instead of P waves, “fibrillation waves” may frequently be seen on the ECG.

It is not unusual to have a pause and/or a bradycardic rhythm result if AF suddenly ceases, especially in elderly patients.

This situation is part of a sinus node abnormality called “sick sinus syndrome” and can frequently require a pacemaker to treat. AF is classically characterized by an _______ _______ ventricular response.

There are no ___ _______ in AF.

IRREGULARLY IRREGULAR
P WAVES
A “cousin” of AF is atrial flutter. With this rhythm the atria again beat rapidly but in an organized fashion between 240 and 300 bpm. Again no P waves are seen but classic “saw-tooth” flutter waves are frequently discernible on the ECG in a typical variety. Typical atrial flutter comes from a single reentrant electric circuit (like a dog chasing its tail) in the RA.

Both AF and atrial flutter may make the ventricles beat very rapidly depending on how fast the AV node allows signals to be transported to them.

Typical atrial flutter is characterized by ______ flutter waves on the ECG.

The atria beat in an _______ fashion in atrial flutter.

AF and atrial flutter may both make the ventricles beat very ________.

**SAW TOOTH**

**ORGANIZED**

**RAPIDLY**
In certain circumstances the ventricles may beat very rapidly on their own from a single source in either the LV or RV. The ventricular rhythm may be organized and occur at rates from 110 to 250 bpm. This is called “ventricular tachycardia” (VT).

VT may cause significant symptoms and can be deadly if it is sustained!

The rate of VT is generally _____ to _____ bpm.

If it is sustained _____ can cause significant symptoms or even death!

110, 250

VT
Another rapid ventricular rhythm, this one completely chaotic (i.e., akin to AF but in the ventricles), is “ventricular fibrillation.” This rhythm renders the heart ineffective in producing any organized pumping action and is deadly if it is sustained and not treated!

VF produces no ______ pumping action and is ______ if sustained and not treated!

ORGANIZED, DEADLY
THE "BLOCKS"

The interval from the beginning of the P wave to the onset of the QRS complex is called the “PR interval.” It is an important measurement because prolongation of the interval is indicative of a delay, or “block,” in electrical conduction at some point between the atria and the ventricles.

“First-degree” AV block occurs when there is a fixed prolongation of the PR interval greater than 200 ms (>1 big ECG grid box).

With first-degree AV block there is a ventricular beat for every atrial beat, or in other words, each atrial beat conducts down to the ventricles.

The PR interval is measured from the beginning of the ______ to the onset of the ______ complex.

The PR interval is greater than _______ ____ and is _______ in first-degree AV block.

Each atrial beat _______ conduct to the ventricles in first-degree AV block.

**P WAVE, QRS**

200 ms, FIXED

DOES
“Second-degree AV block” occurs when sinus beats intermittently do not conduct to the ventricles. It comes in two basic varieties, “Mobitz type I” and “Mobitz type II.”

There is a gradual prolongation of the PR interval with each successive beat before conduction block to the ventricles occurs with second-degree AV block Mobitz type I.

The PR interval remains fixed in second-degree AV block Mobitz type II before conduction does not occur. This may result in single or multiple nonconducted beats, as in below.

With second-degree AV block P waves are _________ not conducted to the ventricle.

The PR interval is fixed in Mobitz type ____ and progressively lengthens in Mobitz type ____ second-degree AV block before conduction block occurs.

**INTERMITTENTLY**

II, I